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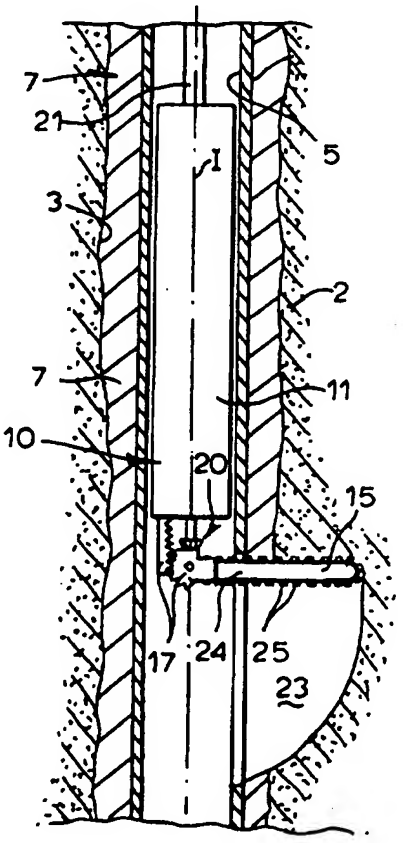
(57) Abstract

A cutting device for making a slot adjacent to a well traversing an underground formation comprises a chain saw arm (15) which carries an endless chain (24) with cutting elements (25). In use the chain (24) is rotated around the arm (15) while the arm (15) is gradually hinged from a longitudinal towards a lateral position relative to the wellbore thereby inducing the cutting elements (25) to cut a slot through the formation (2) and well casing or liner (5), if present.



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# DEVICE AND METHOD FOR MAKING A SLOT IN AN UNDERGROUND FORMATION

The present invention relates to a device and method for making a slot adjacent to a well traversing an underground formation.

In the art of completion of wells for the production of oil and gas it is often necessary to perforate the formation and/or well casing and surrounding cement annulus in order to permit flow of fluid from the formation into the wellbore.

It is common practice to make such perforations by means of shaped charge perforating guns which fire a jet of metal particles at high speed through the casing and cement sheath into the surrounding formation.

Numerous attempts have been made to create devices which are able to cut slots adjacent to an underground wellbore which do not distort and compact the surrounding formation to the extent as occurs with perforating guns.

USA patent specification No. 3 225 828 discloses a downhole slot cutting device comprising a circular slot cutting wheel. During use of the known device the cutting wheel is rotated while moving it partly outside its housing to cut a slot in the surrounding casing or wellbore, whereupon the cutting wheel is retracted again into the housing and the device is withdrawn from the well. Other devices employing a circular slot cutting wheel are disclosed in US patent specifications No. 4,106,561 and 4,220,201.

A drawback of the known slot cutting devices is that the depth of the slot made in the underground formation is relatively small as the maximum extension of the cutting wheel is less than 50% of the diameter of the borehole.

It is an objective of the present invention to provide a device and a method which make it possible to increase the area and depth of the slot made adjacent to a well traversing an underground

formation so as to improve the communication between the wellbore and the surrounding formation.

The apparatus according to the invention comprises a saw arm which is hingeably joined to a housing such that the saw arm is hingeable between a first position wherein the saw arm extends substantially parallel to a longitudinal axis of the housing and a second position wherein the saw arm extends in a direction away from the longitudinal axis of the housing. The saw arm is equipped with an endless chain on which a series of cutting elements are mounted and with means for inducing the chain to rotate around the saw arm.

Preferably the saw arm is formed by an oblong blade and the means for inducing the endless chain to rotate around the saw arm comprises a drive shaft which is driven by a hydraulic positive displacement motor of the Moineau type. In order to hinge the arm while rotating the chain the device may comprise a hydraulic piston assembly and a hingeing mechanism which induces the saw arm to gradually hinge towards the second position in response to the hydraulic pressure difference across the motor and a spring mechanism is present which induces the saw arm to hinge back towards the first position in the absence of a hydraulic pressure difference across the motor.

Preferably the hingeing mechanism comprises a spur gear which is fixed to the supported end of the saw arm, and the piston assembly carries a teethed bar of which the teeth cooperate with the spur gear.

The method according to the invention comprises the steps of lowering into the well a cutting device comprising a saw arm which is hingeably joined to a housing and which carries an endless chain provided with cutting elements; and inducing the endless chain to rotate around the saw arm while gradually hingeing the saw arm from a first position in which the saw arm extends substantially parallel to a longitudinal axis of the housing towards a second position in which the saw arm extends in a direction away from said longitudinal axis. After completion of cutting the slot the saw arm is hinged back to the first position and the cutting device is withdrawn from

the well or moved towards another downhole location where a slot is to be cut.

The invention will be described by way of example in more detail with reference to the accompanying drawings, wherein

Figure 1 shows schematically and not to scale a partial cross-section of a vertical well wherein the cutting device according to the present invention is arranged; and

Figure 2 shows schematically a partial cross-section of the cutting device, drawn to a scale which differs from the scale of Figure 1.

Reference is now made to Figure 1 showing a well 1 traversing an underground formation 2. The well 1 comprises a borehole 3 in which a casing 5 has been installed. The annular space between the casing 5 and the wall of the borehole 3 is filled with cement 7.

The cutting device 10 of the present invention comprises a housing 11 and a saw arm 15 which is hingeably joined to the housing 11. The saw arm 15 is surrounded by an endless chain 24 provided with cutting elements 25. The cutting device 10 further includes a device 17 for hingeing the saw arm 15 relative to the housing 11, a motor (not shown), and a transmission system 20 for inducing the endless chain 24 to rotate around the saw arm 15.

The cutting device 10 is suspended within the well 1 at the lower end of a pipe 21. During lowering the cutting device 10 into the well 1, the saw arm 15 is maintained in a first position wherein the saw arm 15 extends parallel to the longitudinal axis I of the housing 11. When the cutting device has arrived at the location where a slot is to be cut in the casing 5 and surrounding formation 2, the motor is activated to drive the endless chain 24. Simultaneously the saw arm 15 is gradually hinged towards a second position wherein the saw arm 15 extends in a direction away from the longitudinal axis I of the housing 11. As shown in Figure 1, in the second position the saw arm 15 extends perpendicular to the longitudinal axis I of the housing 11. Then the cutting device 11 is displaced upwards through the well 1, and the cutting elements 25 on the endless chain 24 cut an elongated slot 23 through the casing 5,

the cement annulus 7 and the surrounding formation 2. When the elongated slot 23 has obtained its desired length, the saw arm 15 is hinged back to the first position, and the cutting device 10 is withdrawn from the well 1. The surface area on each face of the elongated slot 23 is the length of the elongated slot 23 times the depth of the slot 23 which is the dimension of the slot perpendicular to the well 1.

The length of the saw arm 15 is so selected that the depth of the elongated slot 23 is between 0.25 and 3.0 times or greater than the diameter of the drilled borehole 2, and suitably between 0.5 and 1.50 times the diameter of the drilled borehole 2.

The cutting device 10 shown in Figure 1 will be described in more detail with reference to Figure 2. The cutting device 10 comprises a housing 11 and a saw arm 15, which is hingeably joined to the housing 11. The saw arm 15 is rotatable between a first position wherein the saw arm 15 extends parallel to the longitudinal axis of the housing 11 and a second position wherein the saw arm 15 extends in a direction away from the longitudinal axis of the housing 11, as shown in Figure 2.

The cutting device further includes a device 17 for hingeing the saw arm 15 relative to the housing 11, and a motor 27 provided with a splined telescopic output shaft 28 and a transmission system 20 for inducing an endless chain 24 provided with cutting elements 25 to rotate around the saw arm 15.

The endless chain 24 passes over a pulley or socket wheel 29 which is arranged at the supported end of the saw arm 15. The pulley or socket wheel 29 is connected to a drive shaft 30, which is rotatably joined to the housing 11 by a bearing assembly (not shown). The direction of the drive shaft 30 is perpendicular to the longitudinal axis I of the housing 11, and the saw arm 15 is hingeably joined to the drive shaft 30.

The drive shaft 30 is in its turn driven by the transmission system 20. The transmission system comprises a straight or helical bevel gear, having a driven gear wheel 31 joined to the drive shaft 30 and a driving gear wheel 32 attached to the lower end of the

telescopic output shaft 28 of the motor 27. The telescopic output shaft 28 is supported near the driving gear wheel 32 by means of a support (not shown) that prevents axial and lateral displacement of the end of the telescopic output shaft 28.

The device 17 for hingeing the saw arm 15 includes a device 35 causing a bar 37 to translate in the longitudinal direction of the housing 11 and a device 39 which converts the translation of the bar 37 into rotation of the saw arm 15. The device 39 comprises a spur gear 40 co-operating with teeth 41 on the bar 37. The spur gear 40 is provided with an arm 42 which is joined to the saw arm 15 to transmit the rotation of the spur gear 40 to the saw arm 15.

The device 35 causing the bar 37 to translate in the longitudinal direction of the housing 11 comprises a piston 45 provided with an opening 46 and a tubular driver assembly 48, which tubular driver assembly 48 comprises an outer tube 49 and an inner tube 50. The upper end of the outer tube 49 is joined to the piston 45 and the bar 37 is joined to the lower end of the inner tube 50. The housing 11 is provided with an inwardly protruding ring 52, and the outer tube 49 is provided with a shoulder 53 so that the movement of the device 35 is limited between the first position wherein the shoulder 53 is in contact with the inwardly protruding ring 52 and the second position wherein the piston 45 is in contact with the inwardly protruding ring 52. The toothed bar 37 and the spur gear 40 are so designed that in the first position the saw arm 15 is in the direction of the housing 11 and that in the second position the saw arm 15 extends perpendicular to the housing 11.

The housing is furthermore provided with an inwardly protruding support ring 55, and the inner tube 50 is provided with an outwardly protruding ring 56. In the annular space 60 between the inner tube 50 and the housing 11 two springs are arranged: a return spring 62 located between the inwardly protruding support ring 55 and the outwardly protruding ring 56, and a compression spring 64 arranged between the outwardly protruding ring 56 and the lower end of the outer tube 49. The two springs 62 and 64 are to provide a slightly floating suspension of the chainsaw arm 15 which allows the chainsaw

to respond to hard spots in the casing and/or surrounding cement lining and formation.

The motor 27 is fixed to the inner tube 50 by means of supports 67 and 68, and the telescopic output shaft 28 of the motor 27 extends through opening 70 in plate 71.

The motor 27 is a hydraulic positive displacement motor of the Moineau type. The motor 27 is arranged co-axially to the longitudinal axis I of the housing 11. The upper support 67 is a ring that prevents fluid for powering the motor 27 from leaking away.

During normal operation, the cutting device 10 is lowered into the well 1 (see Figure 1) at the lower end of pipe 21. During lowering the cutting device 10 the saw arm 15 is in the first, co-axial position relative to the longitudinal axis I. Then the motor 27 is activated by passing a driving fluid through the pipe 21, this fluid passes via opening 46 into the positive displacement motor 27. The telescopic output shaft 28 of the motor 27 drives the endless chain 24 with the cutting elements 25 via the transmission system 20.

The fluid supplied through the pipe 21 also acts on the piston 45, and as a result the device 35 for causing the bar 37 to translate moves downwards, and the saw arm 15 will gradually hinge towards to a position away from the longitudinal axis I of the housing 11. When the saw arm 15 is rotated the cutting elements 25 cut through the casing 5 (see Figure 1), the cement layer 7 and the underground formation 2. When the saw arm 15 extends in the desired lateral direction relative to the longitudinal axis I, the cutting device 10 is pulled upwards to form the elongated slot 23 in the underground formation 2.

When the elongated slot 23 has got its desired length, the supply of fluid is interrupted, and the return spring 62 forces the device 35 for causing the bar 37 to rotate upwards so that the saw arm 15 returns to its first, co-axial position. Thereupon the cutting device 10 can be removed from the well 1.

The length of the saw arm 15 is not limited by the diameter of the housing or of the borehole, therefore the depth of the slot can be made much greater than the depth that can be made with the known cutting devices which employ a circular cutting blade. Moreover, the elongated slot of the present invention has flat walls, therefore application of a slot results in a production gain of at least 25% when compared to conventional perforations having the same depth which are created by means of a perforating gun. The elongated slots made in accordance with the method of the present invention also improve any further treatment of the well such as gravel packing, hydraulic fracturing and other stimulation treatments. When slots according to the invention are used in combination with gravel packing substantially higher gains (up to 300%) can be expected due to the absence of a crunched zone with fines that tend to plug the gravel filter perforation tunnels made with conventional perforating techniques.

The cutting device can be provided with a conduit system and with nozzles that distribute fluid used to drive the motor to the cutting elements for cleaning them.

By selecting a proper density of the fluid in the well, the fluid pressure near the saw arm can be controlled. The pressure can be larger than the formation pressure to facilitate cutting the formation. Alternatively the pressure can be less than the formation pressure, and fluid will flow from the formation into the well and this fluid will clean the cutting elements.

The motor of the device described with reference to Figure 2 is a hydraulic, positive displacement motor, but instead the motor can be a hydraulic turbine or an electric motor. In case the motor is driven by a fluid, the cutting device will be attached to the lower end of a pipe such as a drill pipe or a coiled tubing. In case the motor is an electric motor the cutting device is attached to the lower end of an electric line or a coiled tubing provided internally with an electric line. Alternatively the cutting device can be provided with a transmission system that transmits rotation of the

pipe on which the device is lowered into the well to the endless chain.

The bar 37 can be replaced by a rotatable spindle driven by an electric motor, which spindle co-operates with the spur gear.

The cutting device according to the present invention can be equipped with more than one saw arm, for example with two symmetrical saw arms. In such case the second saw arm (not shown) may be hingeable about the drive shaft 30 and may be induced to hinge by means of a spur gear which is driven by a toothed bar. Such toothed bar and spur gear may be arranged in a mirror position with respect to the spur gear 40 and toothed bar 37 as shown in Figure 2.

As described with reference to Figure 1 the cutting elements cut through the casing, the cement and the formation. It will be understood that when the well is completed with a liner, the cutting elements will cut through the liner, and that when the well is an open hole the cut will only be made in the formation.

Furthermore, if the well contains a steel casing or liner the device may be equipped with a circular saw blade which first cuts a slot in the casing or liner and the chain saw is then hinged through the thus cut slot to cut a slot in the cement lining and surrounding formation.

The well as shown in Figure 1 was a vertical well, however, the application of the cutting device according to the present invention is not restricted to vertical wells. The well can also be an inclined or horizontal well, in which case the term 'upwards' means 'into a direction nearer to the wellhead'.

Depending on the motor and the transmission system the endless chain can rotate in two directions.

The elongated slot can be made travelling upwards (as described with reference to Figure 1) or downwards.

The cutting elements 25 are made of wear-resistant material, such as tungsten carbide, or natural or synthetic diamond.

It will be understood that there are numerous possibilities to create a hingeing mechanism which gradually hinges the saw arm 15 towards the lateral position shown in Figure 1 while the cutting

elements 25 are cutting a slot and which returns the saw arm into the longitudinal position after the slot has been cut.

Thus it is to be understood that the embodiment of the slot cutting device shown in the drawings is illustrative only.

## C L A I M S

1. A cutting device for making a slot adjacent to a well traversing an underground formation, the device comprising a saw arm which is hingeably joined to a housing such that the saw arm is hingeable between a first position wherein the saw arm extends substantially parallel to a longitudinal axis of the housing and a second position wherein the saw arm extends in a direction away from the longitudinal axis of the housing, an endless chain provided with cutting elements surrounding the saw arm and means for inducing the chain to rotate around the saw arm.

2. The cutting device according to claim 1, wherein the saw arm is formed by an oblong blade which has such a length that the depth of the elongated slot is at least 0.5 times the internal diameter of the well.

3. The cutting device according to claim 1 or 2, wherein the means for inducing the endless chain to rotate around the saw arm comprises a drive shaft, which in its turn is driven by a motor.

4. The cutting device according to claim 3, wherein the endless chain passes over a pulley or socket wheel which is rotatably arranged at the supported end of the saw arm, which pulley or socket wheel is mounted on the drive shaft.

5. The cutting device according to claim 3 or 4, wherein the drive shaft is rotatably joined to the housing by a bearing assembly such that the direction of the drive shaft is substantially perpendicular to the longitudinal axis of the housing, and the saw arm is hingeably joined to the drive shaft by another bearing assembly which permits the saw arm to rotate relative to the housing and the drive shaft.

6. The cutting device according to claim 3, wherein the motor is a hydraulic, positive displacement motor arranged in the housing substantially co-axial to the longitudinal axis of the housing.

7. The cutting device according to claim 6, wherein the device comprises a hydraulic piston assembly and a hingeing mechanism which induces the saw arm to hinge towards the second position in response to the hydraulic pressure difference across the motor and a spring mechanism is present which induces the saw arm to hinge back towards the first position in the absence of a hydraulic pressure difference across the motor.

8. The cutting device according to claim 7, wherein the hingeing mechanism comprises a spur gear which is fixed to the supported end of the saw arm, and the piston assembly carries a teethed bar of which the teeth cooperate with the spur gear.

9. A method of making a slot adjacent to a well traversing an underground formation, the method comprising the steps of lowering into the well a cutting device comprising a saw arm which is hingeably joined to a housing and carries an endless chain provided with cutting elements; inducing the endless chain to rotate around the saw arm while hingeing the saw arm from a first position in which the saw arm extends substantially parallel to a longitudinal axis of the housing towards a second position in which the saw arm extends in a direction away from said longitudinal axis rotating the saw arm back to the first position; and withdrawing the cutting device from the well.

10. The method according to claim 9, wherein the saw arm has such a length that the depth of the elongated slot is at least 0.5 times the internal diameter of the well.

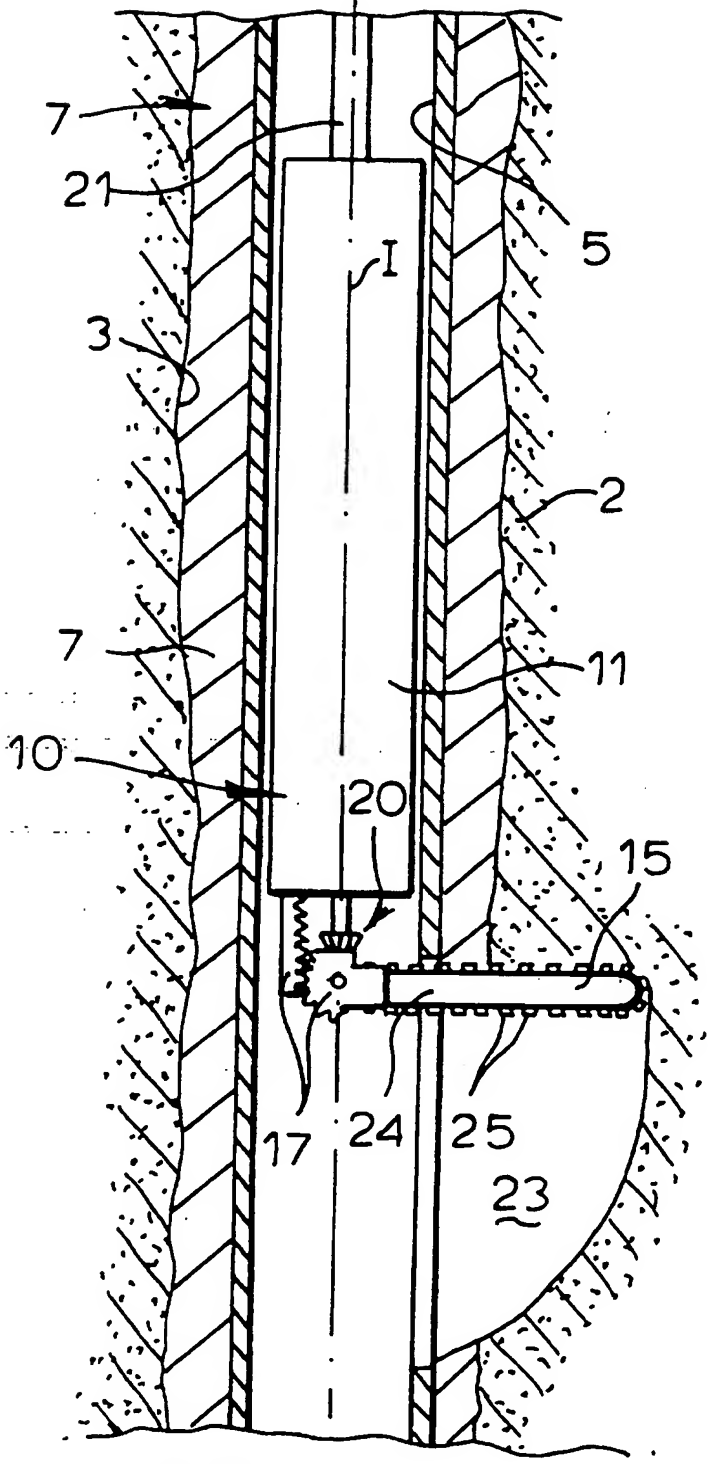


FIG.1

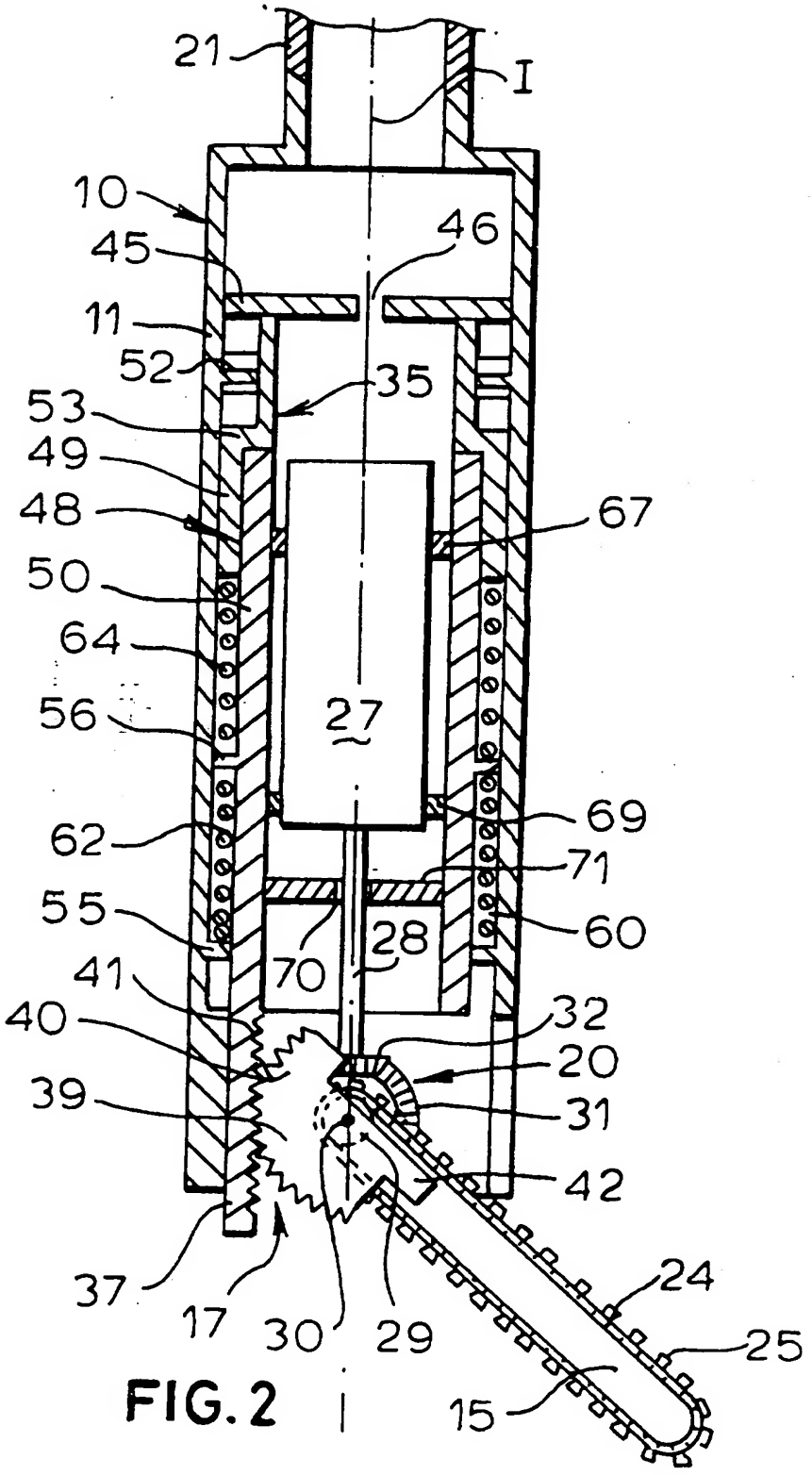
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FIG. 2

# INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E21B11/06 E21B10/32 E21B29/00

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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